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Federal Aviation Administration

Advisory Circular

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1. PURPOSE. This advisory circular (AC) sets forth an acceptable means, but not the only means, of demonstrating compliance with the provisions of Title 14, Code of Federal Regulations (14 CFR) part 25 pertaining to the certification requirements for windshields, windows, and mounting structure. Guidance information is provided for showing compliance with § 25.775(d), relating to structural design of windshields and windows for airplanes with pressurized cabins. Terms used in this AC, such as "shall" or "must," are used only in the sense of ensuring applicability of this particular method of compliance when the acceptable method of compliance described herein is used. Other methods of compliance with the requirements may be acceptable. While these guidelines are not mandatory, they are derived from extensive Federal Aviation Administration (FAA) and industry experience in determining compliance with 14 CFR. This AC does not change, create any additional, authorize changes in, or permit deviations from, regulatory requirements.

2. APPLICABILITY. This advisory circular contains guidance for the latest amendment of the regulations and applies to all transport category airplanes approved under the provisions of part 25, for which a new, amended, or supplemental type certificate is requested.

3. RELATED DOCUMENTS.

a. Title 14, Code of Federal Regulations (14 CFR) part 25.

§ 25.775 Windshields and windows.

§ 25.365 Pressurized compartment loads.

§ 25.773(b)(2)(ii) Pilot compartment view.

§ 25.571 Damage-tolerance and fatigue evaluation of structure.

4. DEFINITIONS.

a. Annealed glass. Glass that has had the internal stresses reduced to low values by heat treatment to a suitable temperature and controlled cooling.

b. Chemically toughened glass. Annealed glass immersed in a bath of molten salt resulting in an ion exchange between the salt and the glass. The composition of the salt is such that this ion exchange causes the surface of the glass to be distorted (expansion), thus putting the surface in a state of compression.

c. Creep. The change in dimension of a material under load over a period of time, not including the initial instantaneous elastic deformation. The time dependent part of strain resulting from an applied stress.

d. Cross-linking. The setting up of chemical links between molecular chains.

e. Modulus of Rupture (MOR). The maximum tensile or compressive longitudinal stress in a surface fiber of a beam loaded to failure in bending calculated from elastic theory.

f. Mounting. The structure that attaches the transparent elements to the aircraft structure.

g. Notch sensitive. The extent to which the sensitivity of a material to fracture is increased by the presence of a surface non-homogeneity, such as a notch, a sudden change in cross section, a crack, or a scratch. Low notch sensitivity is usually associated with ductile materials, and high notch sensitivity is usually associated with brittle materials.

h. Pane/Ply. The pane/ply is a single sheet of transparent material that makes up a windshield or window panel.

i. Panel. The panel is the complete transparency excluding the mounting.

j. Thermally toughened glass. Annealed glass heated to its softening temperature after which the outer surfaces are rapidly cooled in a quenching medium resulting in the outer surface being put into a state of compression with the core material in tension to maintain equilibrium.

k. Toughened glass. Annealed glass placed into a state of compressive residual stress, with the internal bulk in a compensating tensile stress. Toughening may be achieved by either thermal or chemical processes.

5. BACKGROUND. Section 25.775(d) was carried forward essentially unchanged from Civil Air Regulations (CAR) 4b.352(d). Amendment 4b-12, effective May 3, 1962, introduced the fail-safe requirement that codified industry practice. It was noted that fail-safe designs prevented depressurizations in a considerable number of windshield failure incidents. There are few transparent materials for aircraft windshield and window applications, and due to their inherent material characteristics, they are not as structurally versatile as metallic materials. Transparent materials commonly used in the construction of windshields and windows are glass, polymethyl-methacrylate (acrylic), polycarbonate, and interlayer materials. The characteristics of these materials require special engineering solutions for aircraft windshield and window designs.

a. Glass. In general, glass has good resistance to scratching and chemical attack, such as wiper action, solvents, and de-icing fluid. Windshield and window designs, however, should take into account its other unique properties, which are considerably different from metals.

(1) Glass exhibits no sharp change in physical properties when heated or cooled and has no definite melting point.

(2) Unlike metals, glass is a hard brittle material that does not exhibit plastic deformation.

(3) Glass is much stronger in compression than in tension. Fracture will occur, under any form of loading, when the induced deformation causes the tensile stress to exceed the Modulus of Rupture (MOR).

(4) The strength of glass varies with the rate of loading; the faster the rate of loading the higher the strength, as is the case for bird impact loading. In addition, glass fracture stress for a load of short duration will substantially exceed that for a sustained load.

(5) The strength of glass, whether annealed or toughened, can be reduced by edge and surface damage such as scratches, chips, and gouges. Failure is usually initiated at some point of mechanical damage on the surface. However, thermal or chemical toughening can considerably increase the fracture strength of annealed glass.

(6) Thermally toughened glass. The surface of annealed glass may be placed in a state of compression by heating the glass to its softening temperature after which the outer surfaces are rapidly cooled in a quenching medium. As mentioned, this results in the outer surface being put into a state of compression with the core material in tension to maintain equilibrium. The surface compressive layer in thermally toughened glass is approximately 18 percent of the total thickness of the glass. There are limitations on the minimum thickness of glass that can be effectively toughened by thermal processing. Very thin glass can not be effectively toughened by these methods. In general, toughening can increase the MOR of a piece of glass by approximately 3.5 to 20 times. Thermally toughened glass has

significant stored energy within it. This energy is released to a certain extent when the glass fractures. Generally, the higher the stored energy the smaller particles are on fracture. Since thermal toughening leaves the glass with high compressive stresses in its surfaces, all cutting, grinding, or shaping must be done before toughening.

(7) Chemically toughened glass. Chemically toughening glass is achieved by immersion in a bath of molten salt of controlled composition. During the immersion process larger alkali ions in the salt replace smaller alkali ions in the surface of the glass. As a consequence of this unequal alkali ion exchange process, the structure of the surface of the glass is distorted by putting the surface in a state of compression similar to that of thermally toughened glass. Depending on the original glass composition and the bath processing, chemically toughened glass may have a compressive layer from 0.002 to over 0.020 inches regardless of the total glass thickness. The compression stress of chemically toughened glass can be made much higher than it can using thermal toughening. As the compressive layer in chemically toughened glass is much smaller than in thermally toughened glass, the stored energy with in the glass does not cause the same visibility problems after failure. However, as with thermally toughened glass all cutting, grinding, and shaping must be done prior to toughening.

(8) Safety factors necessary on glass components. The safety factors necessary for glass components are significantly higher than for other materials used in aircraft construction because of: the loss of strength with duration of load, the variability in strength inherent in glass, and the thickness tolerances and high notch sensitivity.

b. Polymethyl-methacrylate (acrylic). The acrylic materials used for aircraft transparent structural panels are unplasticised methyl-methacrylate based polymers. There are two basic forms of acrylic materials used in aircraft transparencies, as-cast and biaxially stretched (stretched from a cross-linked base material).

(1) As-cast acrylic material: Forming acrylic material to a certain shape by pouring it into a mold and letting it harden without applying external pressure. Although not as notch sensitive as glass, unstretched acrylics have a notch sensitivity. This unplasticised methyl-methacrylate base polymer has good forming characteristics, optical characteristics and outdoor weathering properties.

(2) Biaxially stretched acrylic material: Stretching acrylic material aligns the polymer chains to give a laminar structure parallel to the axis of stretch, which enhances resistance to crazing, reduces crack propagation rates, and improves tensile properties. Stretching acrylic material reduces the materials formability. In addition, stretched acrylics have less notch sensitivity than unstretched acrylics.

(3) Properties. Compared with glass, these acrylics are soft and tough. In general, increasing the temperature causes decreases in the mechanical properties of the material, except for elongation and impact properties.

(4) Crazing. Both basic forms of acrylics used in aircraft transparencies are affected by crazing. Crazing is a network of fine cracks that extend over the surface of the plastic sheet (it is not confined to acrylic materials) and are often difficult to discern. These fine cracks tend to be

perpendicular to the surface, very narrow, and are usually less than 0.025mm (.001 inches) in depth. Crazing is induced by prolonged exposure to surface tensile stresses above a critical level or by exposure to organic fluids and vapours.

(a) Stress crazing may be derived from: residual stresses caused by poor forming practice; residual surface stresses induced by machining, polishing, or gouging; and prolonged loading inducing relatively high tensile stresses at a surface.

(b) Stress crazing has a severe effect on the mechanical properties of acrylics; however, the effects are reduced in stretched materials.

(c) Stress crazing affects the transparency of acrylics. Generally, stretched acrylic panels will be replaced due to loss of transparency from stress crazing before significant structural degradation occurs.

(5) Chemical resistance of acrylic materials. Typically, acrylic materials are resistant to inorganic chemicals and to some organic compounds, such as aliphatic (paraffin) hydrocarbons, hydrogenated aromatic compounds, fats, and oils.

(a) Acrylic materials are attacked and weakened by some organic compounds such as aromatic hydrocarbons (benzene), esters (generally in the form of solvents, and some de-icing fluids), ketones (acetone), and chlorinated hydrocarbons. Some hydraulic fluids are very detrimental to acrylic materials.

(b) Some detrimental compounds can induce crazing; others may dissolve the acrylic or be absorbed in the material. Crazing induced by solvent and other organic compounds has more severe effects on the mechanical properties than stress crazing. Dissolution of the acrylic and chemical absorption into the acrylic degrades the mechanical properties.

c. Polycarbonate. Polycarbonate is an amorphous thermoplastic with a glass transition temperature about 150°C, which shows large strain-to-break and high impact strength properties throughout the normal temperature range experienced by transport aircraft. Polycarbonate not only has significantly greater impact strength properties but also higher static strength properties when compared to acrylic materials.

(1) Polycarbonate exhibits very high deflections under impact conditions, which can result in higher loading into the aircraft structure, compared to glass or acrylic windshields.

(2) Polycarbonate polymer is very susceptible to degradation by the environment, due to moisture absorption and solvent stress cracking, as well as UV degradation. It is possible to prevent degradation by using good design and production practices and incorporating coatings and other forms of encapsulation. Polycarbonate also suffers from phenomena known as physical aging. This results in

the change from ductile properties to brittle properties that occur when polycarbonate is exposed to temperatures between 80°C and 130°C.

(3) Polycarbonate and stretched acrylic fatigue properties are similar to metals when working (design) stresses are used for operating pressure loading design.

d. Interlayer Materials. Interlayer materials are transparent adhesive materials used to laminate glass and plastic structural plies for aircraft applications. Current choices are limited to plasticized polyvinyl butyral (incompatible with polycarbonate), polyurethane, and silicone. The most commonly used are true thermoplastics, but some polyurethanes and all silicones contain some cross-linking.

(1) Interlayer materials are considered to be nonstructural because they do not directly support aircraft loads. However, glass windshields are often attached to the airframe structure through metal inserts bonded to the interlayer. For such designs the residual strength of the windshield in a condition where all glass plies have failed may be dependent upon the strength of the interlayer. In addition, the shear coupling effectiveness of the interlayer has a great influence on the stiffness of the laminate.

(2) Most interlayer materials are susceptible to moisture ingress into the laminate and are protected by compatible sealants in aircraft service.

(3) Interlayer materials, like structural plies, have a useful service life that is controlled by the surface degradation and removal of the transparency for optical reasons.

6. INTRODUCTION. The recommended methods for showing compliance with § 25.775(d) for typical designs of windshields and windows are given in Section 8, Test and Analysis. Typical designs of windshields and cockpit side windows are laminated multi-plied constructions, consisting of at least two structural plies, facing plies, adhesive interlayers, protective coatings, embedded electro-conductive heater films or wires, and mounting structure. Typically the structural plies are made from thermally or chemically toughened glass, or transparent polymeric materials such as polymethyl-methacrylate (acrylic) and polycarbonate. These plies may be protected from abrasion, mechanical, and environmental damage by use of facing plies and/or protective coatings. The facing and structural plies are laminated together with adhesive interlayer material of poly-vinyl butyral (PVB), polyurethane, or silicone. Cabin window designs are typically multi-paned construction consisting of two structural panes (a main load bearing pane and a fail-safe pane), inner facing panes, protective coatings, and mounting structure. Generally, the two structural panes are made from polymethyl-methacrylate and separated by an air gap. However, there are some cabin window designs that have laminated structural panes. The designs with the structural panes separated by an air gap usually are such that the fail-safe pane is not loaded unless the main pane has failed.

7. GENERAL CONSIDERATIONS FOR DESIGN.

a. Items to be considered in designing the mounting for suitability over the ranges of loading and climatic conditions include but are not limited to:

(1) Deflection of the panes and mounting under pressure,

(2) Deflection of the mounting structure as a result of fuselage deflection,

(3) Differential contraction and expansion between the panes and the mounting,

(4) Deflection of the panel resulting from temperature gradient across the thickness of the panel, and

(5) Long term deformation (creep) particularly of non-metallic parts.

b. Fatigue and stress crazing should be evaluated for assemblies using polymeric structural plies. One way to reduce the occurrence of fatigue and stress crazing is by limiting the maximum working stress level over the complete panel assembly, making due allowance for expected in service deterioration resulting from weathering, minor damage, environmental attack, and the use of chemicals/cleaning fluids. This analysis should be based on:

(1) The appropriate strength of the polymer as declared by the material manufacturer under sustained loading,

(2) The panel assembly maintained at its normal working temperature as given by the windshield/window heating system, if installed, and

(3) The ambient temperature on the outside and the cabin temperature on the inside. The most adverse likely ambient temperature should be covered.

8. TESTS AND ANALYSIS. The windshield and window panels must be capable of withstanding the maximum cabin pressure differential loads combined with critical aerodynamic pressure and temperature effects for intact and single failure conditions in the installation of associated systems. When substantiation is shown by test evidence, the test apparatus should closely simulate the structural behavior (e.g., deformation under pressure loads) of the aircraft mounting structure up to the ultimate load conditions. Analysis may be used if previous testing can validate it. The effects of the following material characteristics should be evaluated and

accounted for in the design and test results: notch sensitivity, fatigue, crazing, aging effects, corrosion (degradation by fluids), temperature, UV degradation, material stability, creep, and the function and working life of the interlayer. An acceptable route for the strength substantiation of a transparency is set out below.

a. Ultimate Static Strength.

(1) Conduct a detailed structural analysis using an appropriate structural analysis method to identify the highest stressed areas of the transparency. Subsequently confirm the structural analysis by loading a representatively mounted and instrumented transparency to ultimate load conditions. The panel should be subjected to the most adverse combinations of pressure loading, including the maximum internal pressure, external aerodynamic pressure, temperature effects, and where appropriate, flight loads.

(2) Establish allowable strength values for each structural ply from relevant coupon or sub-component test evidence with allowance for material production variability, material characteristics, long term degradation, and environmental effects. Check the critical design case to ensure that the allowables are not exceeded by the design ultimate stresses.

(3) In lieu of 8.a.(2) above, perform a test above ultimate pressure load to account for material production variability, material characteristics, long term degradation, and environmental effects. In lieu of a rational analysis substantiating the degree of increased loading above ultimate (1.5 times the pressure load defined in § 25.365(d)), a factor of 2.0 may be used. A separate test fixture may be needed to preclude loading the airframe above ultimate capability.

b. Fatigue. Conventional transparency materials exhibit good intrinsic fatigue resistance properties, but the variability in fatigue life is greater than that in aircraft quality metals. Thus a conventional cyclic fatigue test, but of extended duration, may be used to cover this variability. Testing at an elevated stress level for one aircraft lifetime could also give the necessary assurance of reliability. This approach does require consideration of the endurance of the metal parts of the mounting structure. Another approach that may be used in lieu of testing is to maintain the maximum working stresses in the transparency below values at which fatigue will occur. The maximum working stress level over the complete panel assembly should be shown by supporting evidence not to exceed values consistent with the avoidance of fatigue and stress crazing, considering deterioration resulting from weathering, minor damage and scratching in service, and use of cleaner fluids, etc. Fatigue resistance of the mounting structure should be covered separately as part of the fuselage fatigue substantiation.

c. Fail Safe. Fail safe strength capability of the windshield and window panels should be demonstrated after any single failure in the installation or associated systems. The substantiation should account for material characteristics and variability in service material degradation, critical temperature effects, maximum cabin differential pressure, and critical external aerodynamic pressure. The requirements of § 25.571 for the transparent parts of the windshields or windows may be met by showing compliance with the fail-safe criteria in this AC. Other single failures (besides the transparencies) in the installation or associated systems should also be considered. An acceptable approach for demonstrating compliance is defined by the following method:

(1) Conduct an analysis to establish the critical main pressure bearing ply.

(2) To account for the dynamic effects of a ply failure, test the representatively mounted transparency by suddenly failing the critical ply under the maximum cabin differential pressure (maximum relief valve setting) combined with the critical external aerodynamic pressure with critical temperature effects included.

(a) For transparency failures obvious to the flightcrew, the test pressure may be reduced after initial critical pane failure to account for crew action defined in the flight manual procedures. The failed windshield or window should withstand this reduced pressure for the period of time that would be required to complete the flight.

(b) For transparency failures, which would not be obvious to a flightcrew, the test pressure should be held for a time sufficient to account for the remaining period of flight. During the period of time when the test pressure is held, the effects of creep (if creep could occur) should be considered.

(3) Check the fail safe stresses in all intact structural plies determined in 8c(2) to ensure that they do not exceed the material allowables developed to account for material production variability, material characteristics, long term degradation, and environmental effects.

(4) In lieu of 8c(3) above, to account for material production variability, material characteristics, long term degradation, and environmental effects, additional fail safe testing of the transparency to loads above the fail safe loads following the procedures defined in 8c(2) above should be conducted. In lieu of a rational analysis substantiating the degree of increased loading, a factor may be used, as shown in the table below. The factored loads should be applied after the failure of the critical ply. A separate test fixture may be needed to preclude loading the airframe above ultimate capability. The panel tested in 8c(2) may be used for this test.

(5) Load Factors (applied after the failure of the critical ply):

Material	Factor
Glass	2.0
Stretched Acrylic	2.0
Cast Acrylic	4.0
Polycarbonate	4.0

(6) Other single failures in the installation or the associated systems as they affect the transparency should also be addressed. Such failures include broken fasteners, cracked mounting components, and malfunctions in windshield heat systems.